EXPERIMENTAL STUDIES OF CARDIAC MURMURS.

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In connection with experiments on the production of valvular lesions which have been carried on by one of us[1] during the past year, we have made a series of observations on the cardiac sounds with especial reference to transmission of murmurs in the dog's heart. Having studied the character of the heart sounds of the normal dog we have produced, as far as possible, the lesions commonly observed in man, each in several cases. In other experiments we have made a few observations concerning the development of functional basic murmurs. In the present communication it is our desire to refer to some of the more interesting points which have been brought out by that work which we have already done.

Methods. After etherization, the anterior part of the chest is removed, artificial respiration established, the pericardium opened, and the heart thoroughly exposed.

A special stethoscope (Fig. 1) has been devised, the bell of which is of small diameter (1 cm.), so that the sounds heard over a small organ may be better localized, and long (6.8 cm.), so that it may be placed readily upon the rather deep lying structures.

Position of the Heart. The arrangement of the chambers of the dog's heart when exposed *in situ* is somewhat different from that of the human heart. A much larger part of the anterior surface of the organ is occupied by the left ventricle, while the right auricle occupies a smaller area in the upper right-hand corner, and the tip of the appendage of the left auricle is usually visible below and adjacent to the pulmonary artery, just as it is *not*,[2] as a rule, visible in the human heart despite the orthodox illustrations.

Normal Heart Sounds. The heart sounds of the dog are closely analogous to those of the human being. The first sound over the left ventricle is duller and more muscular; over the right ventricle somewhat more flapping and valvular. With the heart exposed, it is possible to put the stethoscope directly over the aortic and pulmonic rings. The difference in the character of the second sounds, which is so often to be detected in the human being, is here very striking. The second sound at the aortic orifice is of very much greater intensity than that at the pulmonic ring, of a more ringing and musical quality, while the second sound over the pulmonic valves has a deader, more wooden character. This difference is marked and characteristic, so much so as to confirm me (Thayer) in the conviction which I have often expressed, that it is sometimes possible, in the human being, to determine the origin of the second sound to which one is listening, by its character alone—a point which may be of importance in cases in which the second aortic sound is heard best to the left of the sternum.

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[1] MacCallum, Johns Hopkins Hosp. Bull., 1906, xvii, 260.

[2] It should be noted, however, that in some dogs an auricle which was evident *intra vitam*, disappears *postmortem*. Similar conditions may exist in man.

FIG. 1.—Stethoscope with a long bell of small diameter for auscultation of the dog's heart.

Aortic and Pulmonic Stenosis. In our first experiment we produced aortic and pulmonic stenosis. This is a perfectly simple procedure, carried out by the passage of a cord about the vessel just above the valves. This may be tightened to produce any degree of stenosis desired. The production of a stenosis causes the characteristic thrill and rough murmur transmitted upward in the course of the current, just as is observed in man. The experiment differs in no essential point from that which may be performed with a rubber tube attached to a faucet.

A striking and particularly interesting point is the ease with which murmurs may be produced in the pulmonary artery. Very slight pressure over the conus arteriosus or over the artery results in the development of a systolic thrill and murmur immediately beyond the point of pressure. The ease with which these murmurs are produced by pressure suggests immediately that a similar process may account for some of the frequent basic pulmonary murmurs which are heard in man. If systolic murmurs can be produced in man by a degree of pressure over the conus arteriosus as slight, relatively, as that necessary to bring about the same phenomenon in the dog, it is but natural to assume that the resistance offered by the chest wall alone may, in many instances, result in systolic murmurs in the pulmonary area.[3]

Aortic Insufficiency. In eight instances (experiments I, II, IV, V, VI, VII, X, XII) an aortic insufficiency was produced. In all cases a loud diastolic murmur developed at the aortic ring; this murmur sometimes replaced the second sound; sometimes the two sounds were heard in association.

Always loudest at the aortic ring, it was transmitted a short distance upward along the aorta, but best downward toward the ventricle. Over the ventricle the murmur was always much feebler, and in some instances it was inaudible at the apex. In some cases it was heard loudest on the anterior surface of the ventricle at about the middle of the line separating the right and left ventricles; in other instances, it was more distinct around toward the left, just below the pulmonic valves. Sometimes it was feebly audible through the right ventricle. The character of the murmur was exactly the same as that of the souffle of aortic insufficiency in the human being. Especially characteristic was the softness of the sound over the ventricle. The first sound over the left ventricle became dull and humming, just as in aortic insufficiency in man.

In several cases in which, after the production of extensive lesions, the ventricle became dilated and feeble, the murmur diminished greatly in intensity, sometimes disappearing wholly over the ventricle, although still faintly audible at the aortic ring.

In three of these eight cases a soft systolic murmur appeared also at the aortic valves. Marked pulsation of the peripheral vessels occurred just as in man, resulting, in some cases, in an exquisite hammer pulse, with a pistol-shot tone in the femorals.

In one case in which we were studying the basic murmurs in the heart of an animal which had been bled repeatedly and afterward infused with salt solution, there developed an exquisite aortic insufficiency with a double (systolic and diastolic) murmur at the ring and over the left ventricle which was visibly dilated. Later a typical murmur of mitral insufficiency, associated with pulsation of the left auricle was to be made out. A sharp second sound was also audible at the aortic ring. The accompanying tracing (Fig. 2) shows, in an interesting way, the difference between the character of the femoral pulse curve before and after the development of aortic insufficiency. Unfortunately, the cannula in the left auricle had become clogged so that the pulsation of the blood in this cavity with the onset of mitral insufficiency was not recorded. The necropsy, in this case, showed that the valves were intact, although subendocardial hemorrhages in both ventricles were probably evidences of the distention to which the walls had been subjected by the artificial plethora.

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[3] In the discussion upon this communication, Dr. Janeway referred to the frequency of pulmonic systolic murmurs during forced expiration. May it not be that this phenomenon is due in part, at least, to the fact that, by the retraction of the lung, that which normally acts as a cushion between conus and chest wall is removed?

The most interesting points brought out by these cases of aortic insufficiency would seem to be the intensity of the diastolic murmur at the ring and its feebleness over the aorta above and over the right and left ventricles below, a condition in every way analogous to that observed in the human heart, and wholly in accordance with the well-known fact that the murmurs of aortic insufficiency are often very difficult to hear. Especially interesting was the production of a functional aortic insufficiency from dilatation, an observation supporting entirely the conception of those observers who have insisted upon the important part which the muscle of the left ventricle plays in the closure of the aortic ring.

Mitral Stenosis. In two cases (experiments VII and IX) attempts were made to produce a mitral stenosis. It is needless to say that it was impossible to bring about changes in the valve analogous to those in a valvular stenosis in the human being. The nearest approach that was made to this was to apply a clamp at about the position of the mitral ring. The tightening of such a clamp resulted in great distention of the left auricle, rise in pulmonic pressure, and an immediate increase in the intensity of the second pulmonic sound, with a corresponding enfeeblement of the second aortic sound. In one case it was possible, at a certain point of rather moderate tightening of the clamp, to detect a slight presystolic murmur, heard best midway between the clamp and the apex, over the left ventricle. This murmur disappeared with further tightening or with relaxation of the clamp. In the other case no murmur could be produced. The first sound instead of becoming snapping and valvular, as in the characteristic valvular stenosis, became duller and more humming.

Mitral Insufficiency. In six cases mitral insufficiency was produced by tearing the valves or chordæ tendineæ with the knife-hook described elsewhere,[4] which was passed through the auricle or through the carotid (experiments II, IV, VI, X, XI, XII). The production of a mitral insufficiency resulted in the development of a blowing, rather soft, systolic murmur heard with moderate intensity over the left ventricle. This murmur replaced the first sound wholly or in part; its general character was closely similar to the analogous murmur in man.

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[4] MacCallum, loc. cit.

In the dog's heart, however, it is possible to place the stethoscope over the left auricle just beyond the valves at the point at which, theoretically, the murmur should be most intense. This is, indeed, the case, the murmur in most instances being very loud and associated with a thrill of great intensity. The murmur was, in some instances, transmitted to the pulmonary veins of both sides; in one case it was audible over the back of the animal. In one case, with distention of the ventricle, a characteristic murmur of mitral insufficiency developed as a result of dilatation of the ring.

It would greatly simplify the teaching of auscultation of the heart if it were possible to make demonstrations such as the foregoing before the student. For years one of us[5] has been in the habit of employing a very simple mechanism, taught him nearly twenty years ago by a valued teacher[6]—a rubber tube attached to a faucet of running water. By producing any degree of pressure upon the tube at a given spot, and by increasing or diminishing the rapidity of the flow of the fluid, many points of importance with regard to the origin and transmission of cardiac murmurs may be illustrated. Indeed, a student who is really familiar with the anatomy of the heart and surrounding organs, and with the character and theories with regard to the origin of the heart sounds, can, after such a demonstration, work out the diagnosis of the simpler valvular lesions with little assistance. The very simplicity of the demonstration sometimes leads the student to doubt its complete applicability to conditions existing in the living animal. For years I[7] have been in the habit of teaching students that the murmur of mitral insufficiency is doubtless loudest at the mitral ring and just beyond this point in the left auricle—that its intensity at this point is probably great—that there is probably also a well-marked thrill over the left auricle—that the deep position, however, of the left auricle and the mitral ring render these conditions undemonstrable—that the murmur is audible at the apex alone because this is the only point at which it is possible to approach the left ventricle—that the murmur of mitral insufficiency is not, as a rule, very intense because, as in the experiment with the rubber tube, the murmur and thrill diminish rapidly as one passes above the point of constriction. But obvious as such an explanation may seem, it is often difficult to impress the student. What a luminous demonstration it would be if one could supplement the experience with running water with experimentally produced lesions as above described—if it were possible for the student to put his finger and his stethoscope on the left auricle as well as on the apex of the heart.

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[5] Thayer.

[6] Dr. W. W. Gannett, of Boston.

[7] Thayer.

There is no reason why such demonstrations could not be made to small sections of students. We are daily inculcating in our students a wholesome skepticism with regard to all things that are insusceptible of proof; and wherever palpable confirmation of our theoretical explanations of morbid phenomena can be offered, we should not fail to produce it.

In one case of dilated heart a characteristic murmur of mitral insufficiency developed as the result of a dilatation of the ring.

Protodiastolic Gallop Rhythm and Murmur. In one instance (experiment IX) an interesting phenomenon was observed. This experiment was started with the idea of observing whether, with aortic insufficiency, the pressure in the left auricle was increased without coincident mitral insufficiency. Cannulæ were inserted into the left femoral artery, into the appendage of the left auricle, and into the peripheral end of a pulmonary artery. By so doing the heart was rotated over toward the right, while the left auricle was held rather tensely in position by the cannula in the auricular appendage. This appeared to have the effect of placing the heart in a position in which it was, in a way, suspended by the left auricle. There then became audible over the left auricle and just below the valves a first, a second, and then, after a momentary pause, a third sound—a diastolic rumble in every way similar to the early diastolic murmur heard in some cases of mitral stenosis. When the heart became more rapid this rumble extended into presystole, simulating, closely, a mitral stenotic murmur. There was no mitral regurgitation. Gradually the murmur disappeared and one heard only a thud, which became clearer with the decreasing rate of the heart's action. One was able to observe the systole of the ventricle immediately followed by the second sound, which occurred while the ventricle was still in a state of contraction. Then followed the sudden dilatation of the ventricle which occurred *abruptly, with a distinct shock, having altogether the appearance of an active muscular process.* Synchronously with this shock occurred the third sound. This thud was clearly analogous in time (*a*) to the so-called *opening-snap* heard in mitral stenosis and ascribed to the sudden tension of the thickened mitral valves with the beginning of diastole. Its character, however, was precisely that of (*b*) the sound in protodiastolic gallop rhythm heard under so many circumstances, especially in nephritis, dilated heart, adherent pericardium, etc., and ascribed variously to the impact of the auricular blood upon a ventricle which has lost its elasticity (Potain),[8] or to an active muscular dilatation of the ventricle (Brauer).[9]

The case is interesting because we were able to *see,* so to speak, the association of this sound with a definite moment in the heart's cycle—that is, the shock of what appeared to be an active diastole, and the association of a murmur with conditions which seemed to suggest the suction of blood into the ventricle.

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[8] Clinique médicale de la Charité, 8°, Paris, 1894, 27.

[9] Verhandl. d. XXI Cong. f. inn. Med., Wiesbaden, 1904, 187.

It may be well here to mention the fact that the presence of a third sound at just this period of the heart's cycle is not infrequent in the apparently normal heart, especially in children. The sound is sometimes a dull thud, sometimes merely a hum, and occurs shortly after the second sound, that is, at the beginning of ventricular diastole. Sometimes it is followed by the faintest suggestion of an echo, so that I[10] have long been in the habit of maintaining that the entrance of blood from the auricle into the ventricle through a normal orifice is associated in some instances with a slightly audible sound.

Basic Systolic Murmurs. In four cases (experiments III, VIII, IX, XI) we have studied the effect of changes in the heart's action on the sounds at the arterial orifices. The question here is too complicated to justify elaborate discussion on the basis of our few experiments, but a brief summary of what we have observed may be of interest.

A. *Aortic Murmurs.*

1. Systolic murmurs at the aortic ring were never found in the normal heart.

2. Variations in arterial pressure produced by nitroglycerin or adrenalin did not result in their appearance.

3. These murmurs appeared in conditions of rather low pressure.

4. In two instances (III and XI) they followed bleeding alone. In such cases the administration of adrenalin with a rise in pressure caused the disappearance of the murmur.

5. Systolic aortic murmurs were especially frequent after infusion of salt solution following bleeding.

6. In general, aortic systolic murmurs were especially frequent after bleeding followed by infusion, in association with what appeared to be rather abrupt action of the ventricle and rather large excursions of the pulse. They sometimes followed hemorrhage alone. They never appeared as the result of modifications in pressure following the administration of nitroglycerin or adrenalin.

B. *Pulmonic Murmurs.*

1. As has been already noted, pulmonary systolic murmurs may be produced with great ease by slight pressure on the conus arteriosus or the pulmonary artery.

2. In two instances a pulmonary systolic murmur developed after considerable hemorrhage.

3. In one instance with a low general pressure following nitroglycerin, a pulmonary systolic murmur developed. The adminis-

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[10] Thayer.

tration of adrenalin and nitroglycerin had, however, but little effect in modifying the pressure in the pulmonary artery.

4. The administration of adrenalin resulted in an increase in systolic pulmonary murmurs when present, during the first strong beats which followed, but during the period of very high pressure occurring in the general circulation, the pulmonary murmurs as well as murmurs at the aortic area, tended to diminish, returning, however, again, if present before, with a fall of pressure at a period when aortic murmurs still remained absent.

5. Infusion of salt solution resulted commonly in the development of systolic pulmonary murmurs.

6. In a general way, conditions which resulted in especially abrupt action of the right ventricle with a large excursion of the pulse wave in the pulmonary artery seemed to favor the development of systolic murmurs at the pulmonary orifice, especially if there had been a preceding hemorrhage followed by infusion of salt solution.

Murmurs were produced more readily in the pulmonary artery than in the aorta, notwithstanding the very slight variations in pressure which occur in the lesser circulation. This was probably due, at least in part, to the fact that with a more or less indistensible ring, the pulmonary artery beyond is much less resistant than the aorta, and capable of greater dilatation with ventricular contractions of moderate force, thus producing, just beyond the pulmonary ring, those conditions favorable to the development of fluid veins, and consequently a thrill and murmur.

In general, our observations seem to show that a change in the character of the circulating blood, such as that which results in the replacing of a considerable quantity of blood by salt solution (diminished viscosity?)is extremely favorable to the development of systolic murmurs at the base.

In conclusion, it may not be amiss to repeat that we have been strongly impressed, during these studies, with the feeling that where auscultation is taught in small sections, several exercises in the study of experimental cardiac murmurs in the dog would do more toward making clear in the mind of the student the essential facts, without which rational diagnosis of cardiac lesions is impossible, than any other method of instruction with which we are familiar.